power plant in Moscow at Cheremushinskaya. Twenty years ago it was belching black, sulfurous smoke. Now it is clean, burning natural gas from Kazakhstan; but how long this gas will last is unclear, as it is also needed for domestic purposes.

Sakharov in particular was concerned about keeping down air pollution. He held that coal probably produces many more cancers than nuclear power, and that the Harrisburg accident killed no one, and is not known to have caused even one cancer. He accepted my estimate of 3,000 cancers a year from air pollution in the United States, based upon a proportional relation of effect to dose, and of perhaps ten times that many bronchial and other medical problems.

Sakharov asked about the doses received at Three Mile Island. My response of 3,000 man–rem (the official estimates are now 800 man–rem) conformed to what he had heard, but he was surprised that so small a dose had caused so much public concern. He compared it at once to doses from bomb tests—which of course he knows well. Each bomb test gives a much higher dose, and the dose commitment to the end of the century from past bomb tests is about 40 millirem per person (10^8 man–rem worldwide).

Sakharov commented that "nuclear weapons pose moral problems: the problems of nuclear power are only those of arithmetic," and went on to ask why the Western press did not educate the public about the advantages of nuclear electric power in simple terms. It was clear to me that even those who have been exposed to the West do not understand our concept of freedom of the press. They find it hard to realize that the press and television do not feel it to be their duty to educate people to the official government position. Sakharov then pressed me further: Why do not more scientists educate the public in this way? I explained that I endeavor to do so, and described my problems in debating with George Wald, a professor emeritus of biology at Harvard, who in a radio debate with me made the factually incorrect statement that "plutonium is the most toxic substance known to man." (Radium is more toxic.) Sakharov understood my difficulty in responding to someone who has, by virtue of his Nobel prize, greater prestige.

It is clear, then, that the Soviet Union is unlikely to be deflected from its plans to develop nuclear power because of the kind of controversy we are having in the West. Even those Soviet citizens who dissent in other matters support the government position on nuclear power. However, I believe the Soviet people to be receptive to discussions of proliferation of weapons and how to control it. □

1. P. L. Kapitsa, Nobel address, January 1978, Stockholm.
2. A. D. Sakharov, "Nuclear Energy and the Freedom of the West," *Bulletin*, 34 (June, 1978), p. 12, *Orange County Reporter*, Jan. 30, 1978.
3. P. L. Kapitsa, *Journal of Experimental and Theoretical Physics*, 30, No. 6 (1970), p. 199.
4. R. Wilson, "How to Have Nuclear Power without Nuclear Weapons," *Bulletin* 33 (Nov., 1977), p. 39;, "Reducing the Proliferation of Nuclear Weapons by Advancing Nuclear Power," in *Policy Gap*, Chicago Council on Foreign Affairs, 1979.
5. J. R. Trabalka, L. D. Eyman, F. L. Parker, E. T. C. Struymen, L. I. Auerbach, *Nuclear Safety*, 20 (1979), p. 206.

ROBERT F. BACHER

A time to find solutions

Carroll Wilson's article, Nuclear Energy: What Went Wrong (*Bulletin*, June 1979), is both interesting and perceptive. He points out quite correctly that at least two of the most criticized areas at the back end of the fuel cycle—reprocessing and nuclear wastes—required much more attention than was given. Also he points out that for nuclear power the whole cycle must work. His comments on control rooms are well taken in addition to his comparison to the vastly more complicated Boeing 747. The quality and training of operators have now been singled out for special criticism in the recent Kemeny Report on the Three Mile Island accident.

Flashing back to the first years of the Atomic Energy Commission there is no doubt that greater attention was focused on problems other than nuclear power. This was not only a reflection of the state of the nuclear program but also a recognition that oil and gas were cheap and plentiful and were rapidly replacing coal. The average wellhead cost of domestic oil was $2.50 per barrel and Middle East oil was a fraction of that. Gas at the wellhead was only about 10 cents per 1,000 cubic feet, equivalent to 60 cents per barrel of oil. Considering also the ease of delivery and use of oil and gas, coal could not compete and neither could nuclear energy.

After an extended study the Atomic Energy Commission announced its first nuclear reactor program in a talk which I gave at a meet-

In the United States, breeder reactors will almost certainly be needed before fusion and solar electric power are commercially available.

ing of the American Academy of Arts and Sciences on February 9, 1949 and summarized in the Academy *Bulletin* as follows:

"These [new reactors] will form the backbone of the United States' reactor development program at the present time. They are:

- A materials testing reactor which, as its name indicates, will be used in the studies of materials to be employed in building reactors.
- A Navy reactor designed as a land-based prototype of a reactor for use in propelling naval vessels of appropriate types.
- An experimental 'breeder' reactor designed to operate with high energy neutrons . . .
- An experimental 'breeder' reactor designed to operate with neutrons of intermediate energy and to explore their possibilities for breeding as well as to produce usable power."

This program looked to the relatively long range future with two of the reactors being breeders, Zinn's experimental breeder reactor (EBR 1) and the Knolls power breeder. The Navy reactor was the land–based prototype of the submarine reactor then being designed by Argonne. The first three of these reactors were all later built as planned and were very successful. Zinn's EBR 1 produced the first electric power from a nuclear reactor. The Knolls power breeder was diverted to become a backup for the submarine program for which, being sodium cooled, it was not exactly appropriate.

The Knolls reactor was dropped as a power breeder. This was unfortunate because to produce *usable* electric power as a breeder the complete cycle would have had to be developed. Thus the problems of the backend of the fuel cycle which later became so urgent could have been encountered much earlier on a more manageable scale. Most experts agree that these problems are solvable.

The most serious problem today for the breeder and for fuel recycling is proliferation of nuclear fuel from which weapons can be made. Wilson does not take up this subject. Some breeding cycles are more proliferation resistant than others but no complete technical solution has been found. Separation or production of nuclear fuel from which weapons can be made is a "dangerous activity," in the language of the Acheson-Lilienthal Report of 1946. Perhaps if this problem had been faced squarely in the intervening years the problem of proliferation would be less critical today.

United States oil production is slowly decreasing and gas production, after receding from a peak some years ago, is relatively constant. Three quarters of our energy now comes from oil and gas. Looking to the future we must stop wasting energy and learn to conserve; we must make more use of coal and reduce its pollution; and we must accelerate the use of solar energy for heat sources. The prospects for producing a significant fraction of our electrical energy from the sun in the next 30 years are not bright. With half of our oil being imported we need new domestic sources of oil and gas, both natural and synthetic.

There is no doubt that we are going to need light water nuclear reactors to produce electrical energy. There seems to be enough domestic uranium to fuel a significant but more modest program for the next 30 years. Both the reactors and their operation must and can be safe. The latter seems to be more difficult than the former. Western Europe needs even more nuclear power and lacks basic uranium. To meet this situation their activities include nuclear fuel reprocessing plants, large breeders and the planned distribution of plutonium. This poses a serious international problem.

In the United States, breeders will almost certainly be needed before fusion and solar electric power are commercially available. Research and development on breeders are needed now for this longer-range future. In the interim the cutback in the light water reactor program gives time to find solutions to the problems of the complete fuel cycle and to safe operation. Hopefully this time can also be used to work toward international agreements to minimize the proliferation of nuclear weapons. □

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